2.1. Introduction.

This chapter discusses the factors that should be taken into account in performing efficiencies measurements, different types of efficiencies and method for efficiencies determination ,assume that there is a source of particles placed a certain distance away from a detector as shown in(Fig.2.1)and that the detector is connected to a pulse-type system.

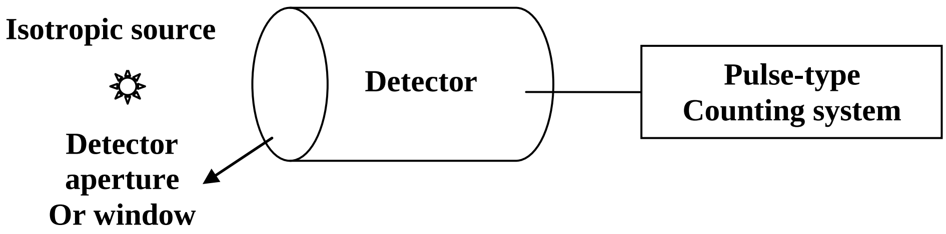

Figure 2.1: a point isotropic counted by a pulse-type counting system [2].

The source may be located outside the detector as shown in (Fig.2.1), or it may be inside the detector and may be isotropic (particles emitted with equal probability in all directions) or anisotropic (a parallel beam of particles).

Let

N=number of particles per second emitted by the source.

r=number of particles per second recorded by the scaler.

It is assumed that the counting rate r has been corrected for dead time and back-ground, if such corrections are necessary. The measured rate r is related to N by (Eq.2.1).

$$r = f_1 f_2 f_3 \ldots\ldots f_n N \tag{2.1}$$

Where the f factors represent the effects of the experimental setup on the measurement. These factors may be grouped into three categories, to be discussed in detail in the following sections.

1- Geometry effects. The term geometry refers to size and shape of source (point, disc, rectangular), size and shape of detector aperture (cylindrical, rectangular, etc.), and distance between source and detector.

2- Source effects. The size and, in particular, the way the source is made may have an effect on the measurement. Whether the source is a solid material or a thin deposit evaporated on a metal foil may make a difference.

3- Detector effects. The detector may effect the measurement in two ways. First, the size and thickness of the detector window and determines how many particles enter the detector and how much energy they lose, as they traverse the window. Second, particles entering the detector will not necessarily be counted .the fraction of a particle that is recorded depends on the efficiency of the detector [2].

2.2. Geometry effects.

The geometry may effect the measurement in two ways. First, the medium between the source and the detector may scatter and may also absorb some particles. Second, the size and shape of the source and the detector and the distance between them determines what fraction of particles will enter the detector and have a chance to be counted [2].

2.2.1. The effect of the medium between sources and detector.

Consider a source and detector separated by a suitable distance. Normally, the medium between the source and detector is air, a medium of low density. For measurements of photons, the air has no effect. If the source emits charged particles, however, all the particles suffer some energy loss, and some of them may be scattered in or out of the detector. If this effect is important for the measurement, it can be eliminated by

placing the source and the detector inside an evacuated chamber. If the use of an evacuated chamber is precluded by the conditions of the measurement, then appropriate corrections should be applied to the results.

2.2.2. The solid angle-general definition.

To illustrate the concept of solid angle, consider a point isotropic source at a certain distance from a detector .Since the particles are emitted by the source with equal probability in every direction, only some of the particles have a chance to enter the detector. That portion is equal to the fractional solid angle subtended by the detector at the location of the source. In the general case of an extended source, the solid angle Ω is defined by (Eq.2.2).

$$\Omega = \frac{\text{number of photons that are enter the detector}}{\text{number of photons that are emitted from the source}} \tag{2.2}$$

And the mathematical expression for Ω is given by (Eq.2.3).

$$\Omega = \int_{\theta}\int_{\varphi} \sin\theta \, d\varphi \, d\theta \tag{2.3}$$

2.3. Source effects.

Two source effects are discussed in this section: absorption of particles in the source, and the effect of the backing material that supports the source, both effects are always important in measurements of charged particles and also significant in x-ray measurements [2].

2.3.1. Source self-absorption factor (f_{self}).

Radioactive substances are deposited on a backing material in thin deposits .but no matter how thin, the deposit has a finite thickness and may cause absorption of some particles emitted by the source. Consider

the source of thickness t shown in (Fig.2.2). Particles 1 traverse the source deposit and enter the detector. Particle 2 is absorbed inside the source so that it will not be counted .therefore, source self-absorption will

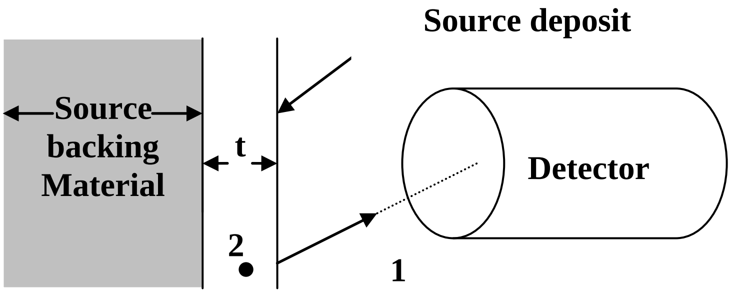

Figure 2.2: source self-absorption particles may be absorbed in the source deposit [2].

Produce a decrease of the counting rate r. source self-absorption may be reduced to an insignificant amount but it cannot be eliminated completely. It is always important for charged particles. Source self-absorption, in addition to altering the number of particles leaving the source; may also change the energy of the particles escaping from it. Particle 1 in (Fig.2.2) successfully leaves the deposit, but it loses some energy as it goes through the deposit. This energy loss is important when the energy of the particle is measured.

A self-absorption factor f_{self} is defined by (Eq.2.4).

$$f_{self} = \frac{\text{number of particles leaving source with self-absorption}}{\text{number of particles leaving source without self-absorption}} \qquad (2.4)$$

2.3.2. Source backscattering factor (f_{back}).

A source cannot be placed in midair .it is always deposited on a material that is called source backing or source support. The source backing is usually a very thin material, but no matter how thin, it may backscatter particles emitted in a direction away from the detector as shown in (Fig.2.3). To understand the effect of backscattering.

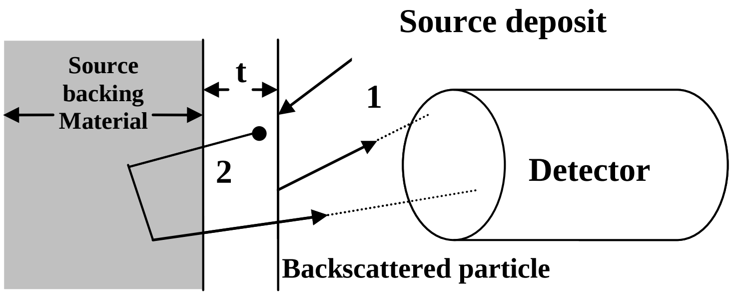

Figure 2.3: The source backing material backscatters particles [2].

Assume that all the particles entering the detector are counted, self-absorption is zero, and there is no other medium that might absorb or scatter the particles except the source backing. Particle 1 in (Fig.2.3) is emitted towards the detector. Particle 2 is emitted in the opposite direction .without the source backing, particle 2 would not turn back. With the backing material present, there is a possibility that particle 2 will have scattering interactions there, have its direction of motion changed, and enter the detector.

A source backscattering factor (f_{back}) is defined by (Eq.2.5).

$$f_{back} = \frac{\text{number of particles counted with source backing}}{\text{number of particles counted without source backing}} \qquad (2.5)$$

The backscattering factor is important, in most cases, only for charged particles. It depends on three variables:

1- Thickness of the backing material.

2- Particle kinetic energy.

3- Atomic number of the backing material.

2.4. Detector effects.

The detector may effect the measurement in two ways. First, if the source is located outside the detector, the particles may be scattered or absorbed by the detector window. Second, some particles may enter the

detector and not produce a signal, or they may produce a signal lower than the discriminator threshold [2].

2.4.1. Scattering and absorption due to the window of the detector.

In most measurements the source is located outside the detector as shown in (Fig.2.4). The radiation must penetrate the walls of the counter and enter it in order to be counted.

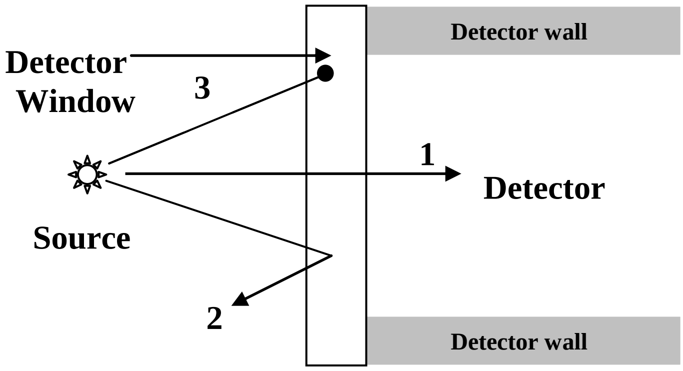

Figure 2.4: The window of the detector may scatter and/or absorb some of the Particles emitted by the source [2].

Interactions between the radiation and the material of which the detector wall is made may scatter and/or absorb particles. This is particularly important for low-energy particles.

(Fig.2.4) shows detector and a source of radiation placed outside it. Usually the particles enter the detector through a window made of a very thin material (such as glass, mica, or thin metal). Looking at (Fig.2.4) most of the particles, like particle 1, traverse the window and enter the counter. But, there is a possibility that a particle, like particle 2, may be scattered at the window and never enter the counter. Or, it may be absorbed by the material of window (particle 3).

In the case of scintillation counters, the window consists of the material that covers the scintillator and makes it light-tight. In some applications the source and the scintillator are placed in a light –tight chamber, thus eliminating the effects of window.

In semiconductor detectors, the window consists of the metallic layer covering the front face of the detector. That layer is extremely thin, but may still affect measurements of charged particles because of energy loss there.

There is no direct way to correct for the effect of the window. Commercial detectors are made with very thin windows but the investigator should examine the importance of the window effect for the particular measurement performed. So there is a need for an energy –loss correction, and correct for the number of particles stopped by the window, that correction is incorporated into the detector efficiency.

2.4.2. Detector efficiency (ε).

It is not certain that a particle will be counted when it enters a detector. It may ,depending on the type and energy of the particle and type and size of detector , go through without having an interaction (particle 1) in (Fig.2.5);it may produce a signal so small it is impossible to record with the available electronic instruments(particle 3);or, it may be prevented from entering the detector by the window(particle 4). In (Fig.2.5), the particle with the best chance of being detected is particle 2.

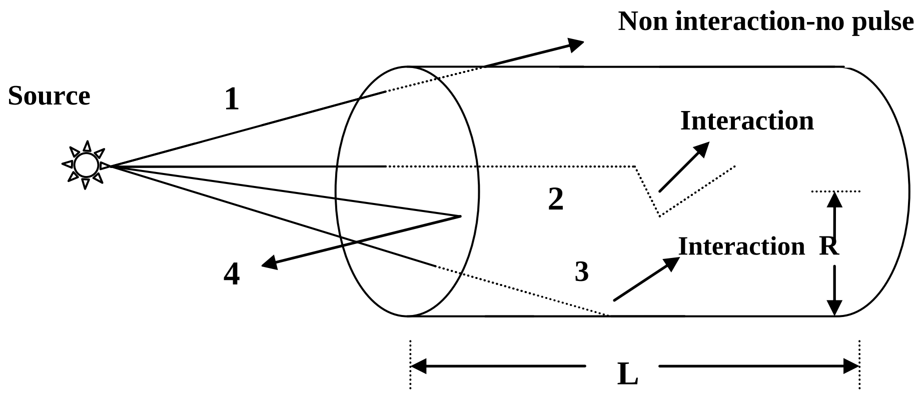

Figure 2.5: particles detected are those interact inside the detector and produce a pulse higher than the discriminator level [2].

The quantity that gives the fraction of particles being detected is called the detector efficiency ε, given by (Eq.2.6).

$$\varepsilon = \frac{\text{number of particles recorded per unit time}}{\text{number of particles impining upon the detector per unit time}} \qquad (2.6)$$

The detector efficiency depends up on

1- Density and size of detector material.
2- Type and energy of radiation.
3- Electronics.

2.4.2.1. Effect of density and size of detector material.

The efficiency of a detector will increase if the probability of an interaction between the incident radiation and the material of which the detector is made increases. That probability increases with detector size. But larger size is of limited usefulness because the background increases proportionally with the size of the detector, and because in some cases it is practically impossible to make large detectors. The probability of interaction per unit distance traveled is proportional to the density of the material. The density of solids and liquids is about a thousands times greater than the density of gases at normal pressure and temperature. Therefore, other things being equal, detectors made of solid or liquid material are more efficient than those using gas.

2.4.2.2. Effect of type and energy of radiation.

Charged particles moving through matter will always have coulomb interactions with the electrons and nuclei of that medium. Since the probability of interaction is almost a certainty, the efficiency for charged particles will be close to 100 percent. Indeed, detectors for charged particles have an efficiency that is practically 100 percent, regardless of their size or the density of the material of which they are made .for

charged particles, the detector efficiency is practically independent of particle energy except for very low energies, when the particles may be stopped by the detector window. Charged particles have a definite range. Therefore, it is possible to make a detector with a length L should be greater than R, where R is the range of the particles in the material of which the detector is made (Fig.2.5).photons traversing a medium show an exponential attenuation, which means that, there is always a nonzero probability for a photon to traverse any thickness of material without an interaction. As a result of this property, detectors for photons have efficiency less than 100 percent regardless of detector size and energy of the particle.

2.4.2.3. Effect of electronics.

The electronics of a detector affects the counter efficiency indirectly. If a particle interacts in the detector and produces a signal, that particle will be recorded only if the signal is recorded .the signal will be registered if it is higher than the discriminator level, which is, of course, determined by the electronic noise of the counting system. Thus, the counting efficiency may increase if the level of electronic noise is decreased.

2.5. Types of the detector efficiencies.

2.5.1. The geometrical efficiency (ε_g).

If there is an isotropic radiating point source emits photons in all directions. Only part of these photons will enter the detector window. The solid angle Ω is subtended between the source and the detector determines the geometrical efficiency ε_g .in general this solid angle Ω depends on both the source and the detector shapes and the distance between them. For isotropic radiating point source the solid angle Ω is

given by “the ratio between the number of photons that enter the detector and the number of photons that are emitted from the source”. The relation which relates the solid angle Ω to the geometrical efficiency ε_g given by (Eq.2.7) [16].

$$\varepsilon_g = \frac{\Omega}{4\pi} \tag{2.7}$$

2.5.2. The intrinsic efficiency (ε_{iT}).

Not all the photons that enter the detector will be recorded in it, but only apart from them depending on the detector dimensions. The photon energy and the detector material type. Therefore “the ratio between the numbers of photons that are recorded in the detector and the number of the photons that enter the detector” [17].

2.5.3. The total efficiency (ε_T).

The total efficiency is defined as “the ratio between the number of photons that are recorded in the detector with any possible energy during a certain time interval and the number of photons that are emitted by the source during the same time interval”. It is related the intrinsic efficiency by (Eq.2.8) [17].

$$\varepsilon_T = \varepsilon_g \, . \, \varepsilon_{iT} \tag{2.8}$$

2.5.4. The intrinsic photopeak efficiency (ε_{ip}).

The intrinsic photopeak efficiency is defined as “the ratio between the number of photons that are recorded under a certain energy peak and the number of photons that enter the detector with energy relates to this peak” [17].

2.5.5. The full energy peak efficiency (FEPE) (ε_P).

Some times called photopeak efficiency (PPE) and defined as “the ratio between the number of photons that are recorded in the detector

under a certain peak and the number of photons that are emitted from the source with energy relates to this peak” [17].

The last two efficiencies are related mathematically by (Eq.2.9).

$$\varepsilon_p = \varepsilon_g . \varepsilon_{ip} \tag{2.9}$$

2.5.6. The double and single escape peak efficiencies (ε_{de},ε_{se}).

After the photon interacts by the pair or triple production the ejected positron may annihilates and two photons with total energy 1.022 MeV appear. If the two photons escape from the detector before interact with it, peak formed is called the double escape peak and its efficiency (ε_{de}) is defined as “the ratio between the number of couple photons escape and the number of photons that are emitted from the source”. If only one photon escapes another peak formed is called the single escape peak and its efficiency (ε_{se}) is defined as “the ratio between the number of single escape photons and the number of photons that are emitted from the source” [18-20]

2.5.7. The photo-fraction (or peak-to-total ratio) (P).

“It is the ratio between the number of photons that are recorded under a certain peak and the number of photons that are recorded in all the spectrum at the same energy”. Which given by (Eq.2.10) [17].

$$P = \frac{\varepsilon_{ip}}{\varepsilon_{iT}} = \frac{\varepsilon_p}{\varepsilon_T} \tag{2.10}$$

2.5.8. Relative efficiency.

It is efficiency of one detector relative to another, commonly that of a germanium detector relative to a 3 in. diameter by 3 in. long NaI crystal, each at 25 cm from a point source, and specified at 1.33 MeV only. And

this may be obtained for all the cases discussed above. In general given by (Eq.2.11) [2].

$$(\text{Relative efficiency})_i = \frac{(\text{The efficiency of the detector})_i}{\text{Efficiency of the standard detector}} \tag{2.11}$$

Where the subscript i refers to any one of the efficiencies defined earlier.

2.6. Energy resolution.

The energy resolution of the detector is determined by measuring the width of photopeak at exactly one-half of the maximum value of the photopeak height, a measurement termed the full width at half maximum (FWHM) (Fig.2.6).

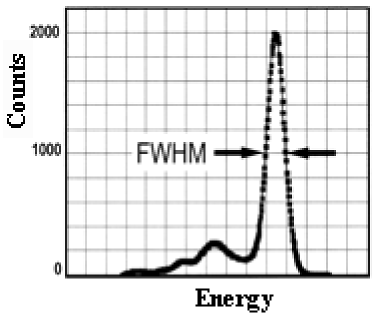

Figure 2.6: The FWHM is measured at exactly one-half of the maximum value of the photopeak [13].

Energy resolution is defined as the FWHM divided by the photopeak energy (PE) and is expressed as a fractional percentage and is given by (Eq.2.12).

$$\text{Energy resolution} = \frac{\text{FWHM}}{\text{PE}} \times 100\% \tag{2.12}$$

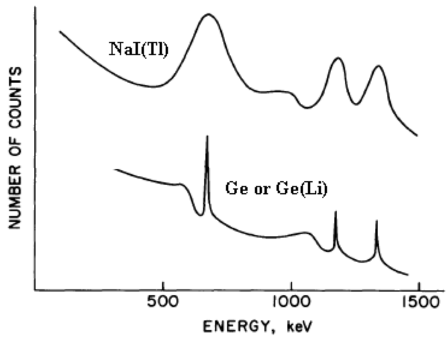

Figure 2.7: Two spectra collected from the same source. one using NaI(Tl) and one using Ge detector [21].

(Fig.2.7) shows two spectra collected from the same source .one using a sodium iodide detector and one using germanium. Even through this is a rather simple spectrum. The peaks presented by the sodium iodide detector are overlapping to some degree, while those from the germanium detector are clearly separated. In a complex spectrum, with peaks numbering in the hundreds, the use of a germanium detector becomes mandatory for analysis [13].